

REDUCTION IN MOTOR-VEHICLE BRAKING TIME DUE  
TO ANGULAR POSITION OF COMBINED  
BRAKE-ACCELERATOR PEDAL

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THESIS

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Due to Angular Position of Combined Brake-Accelerator Pedal

by

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## ABSTRACT

Reduction in frequency and severity of motor vehicle accidents is possible if the reaction time to brake an automobile is reduced. Previous experimentation has shown that reaction time is decreased if brake and accelerator controls are combined into one pedal. The purpose of this experiment was to determine if reaction time changed significantly with changes in angular positions of a combined pedal. Nine angular positions were fixed by combining each of three floor angles with each of three rotational angles.

Measurement of reaction time started when the experimenter turned on a light located directly in front of the subject and ended when the subject depressed the pedal 1/16 of an inch. The fastest mean reaction time was 0.286 sec. at 55° floor angle and 0° rotational angle (55°/0°). This position was significantly better than all other positions except 55°/15°. The time was 35% faster than previously recorded reaction times for the conventional braking system found in cars today.

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## I. INTRODUCTION

The annual death toll from motor vehicle accidents reached a level of 50,000 per year by 1968. The President's National Motor Vehicle Safety Council has issued a policy guideline stressing that the automotive industry must provide new safety features to reduce this toll by 50% during the 1970 decade. A nation with the ability to achieve lunar landings can achieve this reduction.

This loss of life is not restricted to any one segment of the population. However, motor vehicle accidents have become a major source of lost man-days in the military.

"Accidental trauma is a major problem in armed services as well as in civilian life. For example during World War II the United States Army, for the first time in its history, reported more deaths due to accidents than to disease. Every fifth death was related to non-battle trauma, whereas every eighteenth death was related to disease. In the Korean conflict more than half the hospitalized casualties had been injured in accidents rather than by enemy action. Of these casualties 70 percent had been involved in motor-vehicle accidents. The frequency of motor-vehicle fatalities in all branches of the military approximates 2000 cases annually, and accidents now rank as the leading cause of man-days lost." [Bennett, Degan, Spiegel 1963].

Accidents can not be eliminated so long as human beings manufacture and operate automobiles. There are methods by which the severity and frequency of these accidents can be reduced. Methods suggested recently include roadside electronic devices which will transmit warnings concerning road conditions ahead, distance measuring devices to warn drivers they are following another vehicle too closely, and laser beams to alert drivers that they can not back-up safely.

These methods alert the driver that something is about to happen. For the alert signal to be effective the driver must react, and this requires time. The amount of reaction time depends upon the type of response selected. If the driver elects to brake the automobile the distance required to stop can be shortened substantially by reducing reaction time. During the time interval required for reaction to a signal, an automobile continues at the same speed. For example, the stopping distance for an automobile initially traveling at 60 mph (88 feet per second) is shortened 17.6 feet for a 0.2 second reduction in reaction time. But once deceleration begins this reduction in stopping distance will not be as large.

The problem then is to increase traffic safety by reducing reaction time to a warning signal.



## II. BACKGROUND

### A. LITERATURE

With the proper location of controls it would be possible for a driver to brake an automobile with any one of four extremities. It has been shown experimentally that for simple tasks the hand is about 20% faster than the foot, and that the preferred limb is 3% faster than the nonpreferred. It could be concluded that to reduce reaction time to a minimum the brake control should be located near the preferred hand. However, braking an automobile is a complex task [Teichner 1954].

Konz and Daccarett [1967] studied the reaction times for subjects to honk a horn and to depress a brake pedal. The two starting positions were extremities on or off the control to be activated. Their results showed that the foot was 0.01 second slower than the hand when both started on the control, and 0.03 seconds slower when both started off the control. When the left foot started on the brake, reaction time was 0.20 seconds faster than for the right foot starting off the brake. Thus the greatest savings in time can be achieved by elimination of movement of the extremity.

These findings agreed with those of Belzer [1965] who stated that for braking, the left foot will be faster than the right only when the left foot is poised on the brake. Belzer found that the driver had a tendency to leave the right foot on the accelerator when using left-foot braking. This is undesirable since some braking effect is cancelled.

The use of foot controls should be considered in these situations:

- i. When a continuous control task is required but precision of placement is not of primary importance.

ii. When application of forces greater than 20-30 pounds is required.

iii. When there is a possibility of overburdening the hands with the control tasks [Morgan, et.al. 1963].

An operator uses his hands primarily to steer the automobile and in an emergency situation, he must have both hands free to perform this primary task. If hand braking was required the control would have to be placed either on or close to the steering wheel. Since the steering wheel is continually being turned when the automobile is moving, the brake control, if placed on the wheel, would not be in the same position at all times. Regardless of the positioning of a hand operated brake control, the driver would not be able to use his hand for the primary steering task.

The hand is 0.03 second faster than the foot when both start off the control [Konz and Daccarett 1967]. At 60 mph hand braking would decrease stopping distance by 2.6 feet. To overburden the hands for a savings of this magnitude is not realistic.

When small movement forces and continuous operation are required, as in automobile acceleration, the pressure should be applied mainly from the ankle. When large movement forces, i.e., greater than 20 pounds, are required the pressure should be applied along the long axis of the lower leg [Morgan et. al., 1963].

The operation of the foot muscles is such that the major muscles work through the tendons of the heel while lesser muscles work through tendons attached to the front of the foot [Ayoub and Trombley 1967].

All of these factors were considered when designing the combined brake-accelerator pedal tested in this experiment and by West [1969].



In the literature several methods to reduce stopping distances for motor vehicles are discussed. From a human engineering viewpoint the two approaches most frequently discussed are:

- i. Reposition accelerator and brake pedals to reduce foot movement time.
- ii. Develop a combined brake-accelerator pedal which eliminates movement time.

White [1963] mounted a combined brake-accelerator pedal in an automobile but did not remove the conventional brake system. Thus the experimenter was able to select either pedal for testing at any time. The results showed the combined pedal was 115-150 milliseconds faster than the conventional brake for the five subjects tested. On several occasions subjects caught the sole of their shoe on the brake pedal when using the conventional braking system for an emergency stop. The average stopping distance was increased 81 feet when this occurred.

Extensive experimentation has been conducted under the direction of Dr. S. Konz, an associate professor in the Department of Industrial Engineering, Kansas State University. In the first of a series of experiments Konz and Daccarett [1967] showed that movement time for the limb was a critical factor in reducing reaction time.

In their second experiment 121 subjects were tested for reaction time on the Winkleman combined control which activates the accelerator when the toe is depressed and the brake when the heel is depressed. Two-thirds of the subjects were males. The average reaction time for all subjects was 0.42 sec., for males it was 0.41 sec., and for females it was 0.44 sec. There is no significant difference (level not mentioned) between males and females. The times ranged from 0.27 sec. to 0.96 sec.

The selected starting position was accelerator depressed. This control had an interlock to prevent simultaneous operation of the accelerator and brake.

Their third experiment compared reaction times for the Winkleman combined control and the American Automobile Association (AAA) timer. Twenty-five subjects were tested in each of the following situations with indicated results:

- i. AAA timer with starting position of left foot on brake pedal -- 0.29 sec.
- ii. Winkleman combined control -- 0.36 sec.
- iii. AAA timer with starting position of right foot on accelerator -- 0.45 sec.

Situation (i) is significantly ( $p = .05$ ) faster than situation (ii), which in turn is significantly ( $p = .05$ ) faster than situation (iii) [Konz and Daccarett 1967].

For the next experiment the combined control was mounted in a 1960 Rambler, and was interchangeable with the conventional controls. Sixteen subjects were road tested under varying braking situations. Although overall reaction time increased 34%, the combined control was 0.1 sec. faster than the conventional controls [Konz, Kalro, and Koe 1968].

An integrated pedal without interlock was designed by Koe. For the fifth experiment, conducted in the laboratory, the reaction times for this new pedal were compared with times for the conventional Rambler system and with times for the AAA timer. Seventy-two subjects were tested on all three systems with the following results:

- i. AAA reaction timer: starting position was right foot depressing accelerator -- 0.482 sec.

ii. Rambler conventional system: starting position was right foot depressing accelerator -- 0.435 sec.

iii. New integrated pedal: starting position was depressed accelerator -- 0.323 sec.

The new integrated pedal was significantly ( $p = .01$ ) faster than either of the other systems [Konz, Kalro, and Koe 1968].

## B. DEFINITIONS

The following definitions apply to terms in this thesis.

### 1. Reaction Time

Reaction time is defined to include the following elements.

i. Sensing time: the time required to sense a signal. This time is a function of the signal and the sense stimulated.

ii. Decision time: the time required to determine what response to make.

iii. Response time: the time required to respond to the signal. This time is a function of complexity of the response and the body member used [Morgan, et. al., 1963].

### 2. Seat Reference Point

The seat reference point (SRP) is the point where midlines of the seat and backrest intersect [Morgan, et. al., 1963].

### 3. Seat Reference Distance

The seat reference distance (SRD) is the distance measured from the seat reference point along the seat to the front edge and then directly to the heel of the combined pedal.

### 4. Floor Angle

The floor angle is the angle included between the surface of the combined pedal and the floor.

#### 5. Rotational Angle

The rotational angle is the angle included between a vertical mid-sagittal plane through the body and the right side of the combined pedal.

#### 6. Ankle Angle

The ankle angle is the angle included between the sole of the foot and the line between the lateral malleolus (outer ankle bone) and the styloid process.



### III. THE EXPERIMENT

#### A. PURPOSE

This experiment was designed to produce reaction time data for nine angular settings of a combined brake-accelerator pedal. This data would be statistically analysed to determine the angular setting with which subjects achieved the fastest reaction time.

A secondary purpose was to determine if the angular setting of fastest reaction changed with age.

#### B. THE APPARATUS

Two combined brake-accelerator pedals were designed by Dr. G. K. Poock, A. E. West, and T. J. Toben. One pedal was hinged three inches from the heel so that the subject could depress the toe to simulate acceleration. The second pedal was a one-piece plate which rotated about a shaft beneath the plate, 1.5 inches forward of the heel, Figures 1 and 2. These pedals were tested at 45° and 60° floor angles. At the 45° floor angle the one-piece pedal was significantly ( $p = .01$ ) faster than the hinged pedal. At the 60° floor angle there was no significant difference between pedals [West 1969].

The one-piece combined pedal tested by West [1969] was selected for this experiment. The pedal is 3.5 inches wide and 12 inches long. A one-half inch high edge was placed around the heel and right side so that the subject would not have to exert a force to maintain his foot on the pedal during testing.

When the toe of the pedal was depressed a shaft actuated a linear potentiometer which was connected in series with a three volt battery

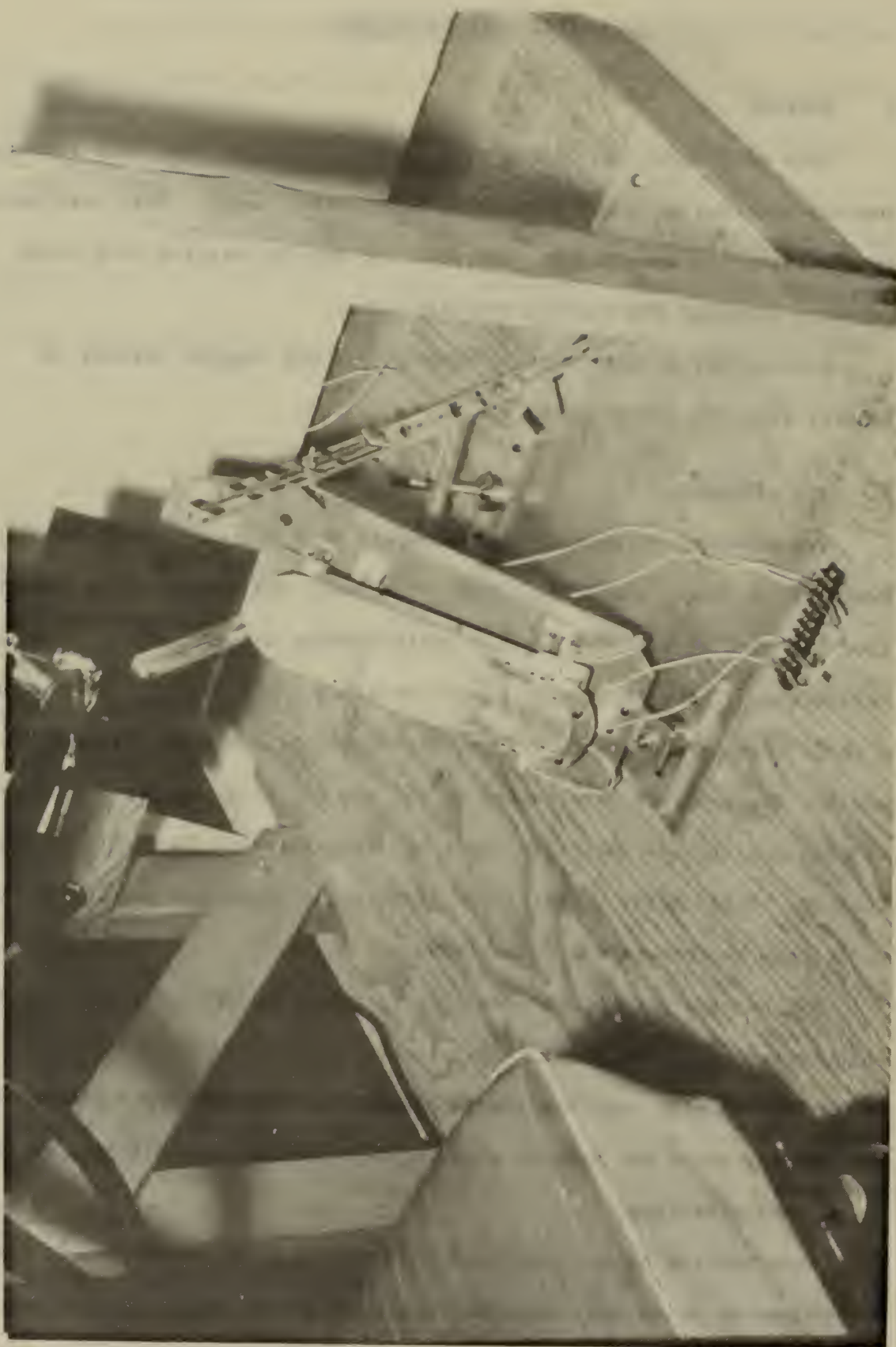


FIGURE 1 ONE-PIECE PEDAL IN POSITION FOR TESTING

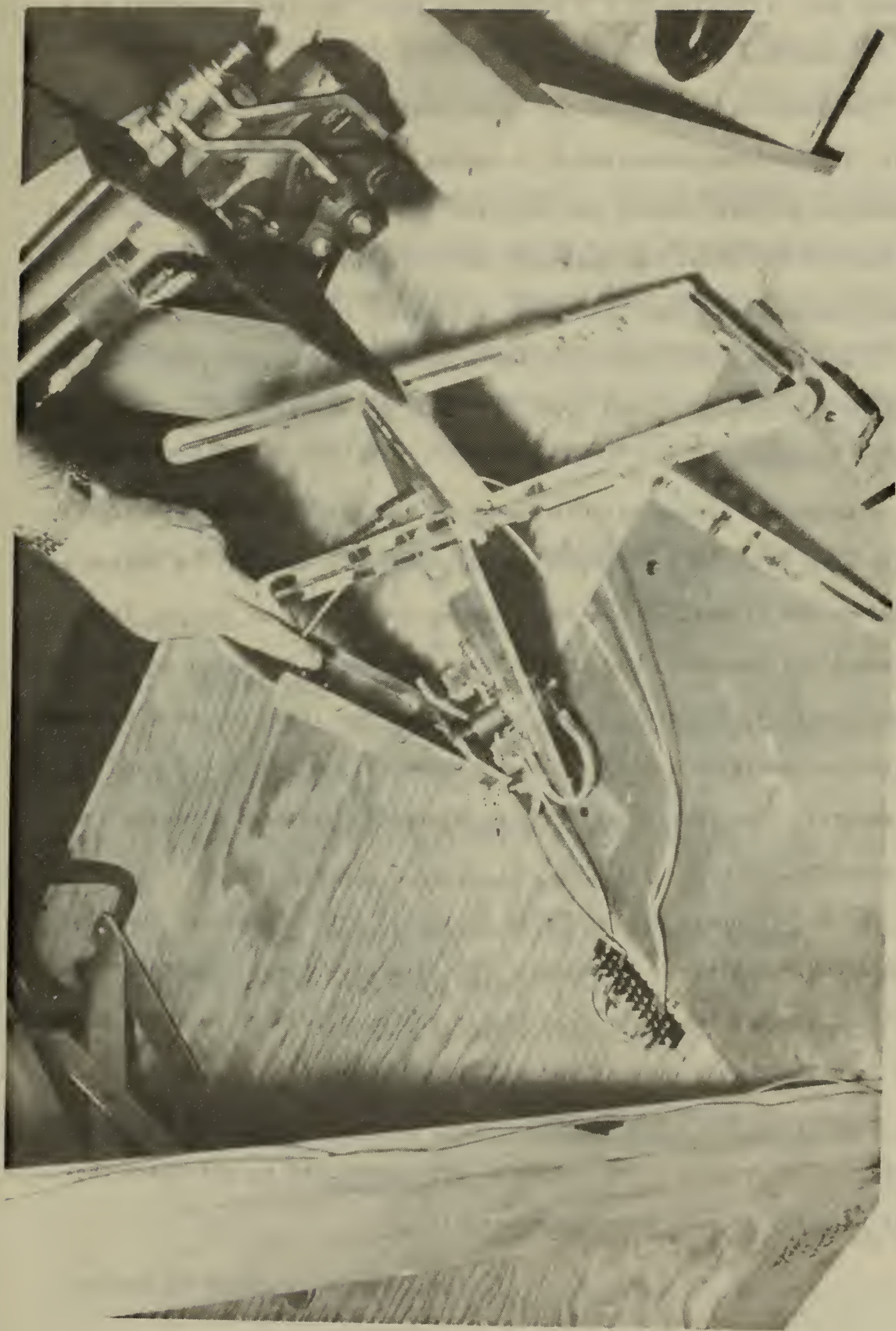


FIGURE 2 ONE-PIECE PEDAL RAISED TO SHOW BRAKE SHAFT



and a voltmeter. The voltmeter was used to simulate a speedometer. A spring, with a tension of 4.5 pounds per inch, returned the pedal to a neutral position when a subject removed his foot.

The pedal pivoted about the brake post 1.5 inches forward of the heel. The heel was supported by a spring with 18 pounds per inch tension. A positive muscular effort was required to overcome this tension. When the heel of the pedal was depressed one-sixteenth of an inch it contacted a micro-switch and pedal travel was stopped.

A sixty-watt red light bulb was placed approximately five feet in front of the subject at eye level. This light provided the action signal in the experiment.

A relay and timing circuit connected the red light and brake micro-switch with an audio oscillator and an electronic counter. A switch was placed in the circuit so the experimenter could turn on the red light and start the counter. When the subject depressed the pedal to contact the microswitch, the counter was stopped and the light turned off. The oscillator generated a 1000 cycle per second signal which was sent to the counter. The reaction time in milliseconds was read directly from the counter.

The seat runners were modified to permit seven inches of longitudinal adjustment in half-inch increments. No direct vertical adjustment was provided, however, when the seat was in the most forward position it was 0.75 inch lower than when it was all the way back from the pedal.

A steering wheel was mounted in front of the subject to enhance the impression of driving. The subjects were instructed to disregard the wheel if using it made them uncomfortable.



## C. SUBJECTS

Thirty-six subjects were randomly selected from male military personnel assigned to the Naval Postgraduate School with the limitation that there were nine subjects in each of four age groups. All subjects served as unpaid volunteers.

Subjects were classified according to age as follows: group 1, 18-24 years; group 2, 25-30 years; group 3, 31-36 years; group 4, 37-52 years. Ages noted are inclusive. The youngest group has a spread of seven years to conform with the change in insurance rates for male drivers. Because of officer assignment policies the youngest group consisted entirely of enlisted personnel, and the other groups consisted entirely of officers.

Each subject held a valid state and/or government operator's license.

## D. VARIABLES

### 1. Independent Variables

The independent variables were either fixed or random. The fixed variables were:

- i. three floor angles - 45°, 55°, 65°;
- ii. three rotational angles - 0°, 15°, 30°;
- iii. group classification of subject's age.

The random variables were:

- i. the seat reference distance;
- ii. height of subject;
- iii. ratio of seat reference distance to subject's height;
- iv. ankle angle;
- v. classification of primary car normally driven by the subject as American or foreign;
- vi. driving experience in years.

Table I gives the relationship between pedal angle and seat reference distance. Seat reference distance was adjustable in fifteen steps of one-half inch each. This distance changes with the floor angle setting because the pivot point for the pedal was approximately 5.5 inches below and one inch behind the heel.

Table II gives the relationship between heel height and angular setting, and the relationship between heel height and seat height.

## 2. Dependent Variables

Reaction time was the dependent random variable. The time interval began when the red light was turned on and ended when the brake pedal contacted the microswitch. Subjects were tested at each combination of floor angle and rotational angle thus yielding nine different test settings. Four observations were obtained at each of the settings for a total of 36 observations per subject.

## E. METHOD

The order in which the nine angular settings were tested was randomized subject to the requirement that each setting be first in a testing sequence an equal number of times. This procedure was adopted to insure elimination of any learning factor.

The subject was seated in the test "vehicle", Figure 3. The experimenter read a prepared statement, Appendix A, explaining the purpose and procedures of the experiment and identifying the equipment.

After the subject placed his foot on the pedal he adjusted the seat so that his leg and foot were comfortable. Then the ankle angle and seat reference distance were measured. Three to five practice runs were permitted before any testing. Practice runs also were permitted when the rotational angle was changed, but were not permitted when just the floor angle was changed.

TABLE I

## Seat Reference Distances

Seat Position	Floor Angle	45°	55°	65°
1		34.0	33.25	32.5
2		34.5	33.75	33.0
3		35.0	34.25	33.5
4		35.5	34.75	34.0
5		36.0	35.25	34.5
6		36.5	35.75	35.0
7		37.0	36.25	35.5
8		37.5	36.75	36.0
9		38.0	37.25	36.5
10		38.5	37.75	37.0
11		39.0	38.25	37.5
12		39.5	38.75	38.0
13		40.0	39.25	38.5
14		40.5	39.75	39.0
15		41.0	40.25	39.5

- Notes:
1. Distances are measured in inches.
  2. Position 1 is seat full forward.
  3. At a given floor angle the distances remained constant for all rotational angles.

TABLE II

Vertical Distance from Pedal to Seat Cushion

Pedal Setting	45/0	55/0	65/0	45/15	55/15	65/15	45/30	55/30	65/30
Pedal Height	5.8	5.9	5.9	5.8	5.8	5.8	5.6	5.6	5.6
Vertical Distance	11.2	11.1	11.1	11.2	11.2	11.2	11.4	11.4	11.4

## Notes:

1. Pedal settings shown as floor/rotational angles.
2. All measurements are in inches.
3. Pedal height is measured from floor to the heel of the pedal.
4. Vertical distance between heel of pedal and top of seat is for seat in full forward position. Add 0.75 inch for seat in full back position.





FIGURE 3 SUBJECT IN TEST "VEHICLE" READY FOR TESTING

The alerting signal "stand-by" was given when the subject had depressed the toe of the pedal so that the needle on the voltmeter was between two red lines thus simulating a speedometer. This insured a common starting position of the pedal. Between two and eight seconds after the alerting signal the red light was turned on and simultaneously the counter was started. The time needed by the subject to depress the brake pedal to stop the counter was the recorded dependent variable.

An alert signal was considered necessary because there was no intent to include the subject's acquisition time, that is the interval between the time the light was turned on and the time the subject saw that the light was on. However, it was not desired that the subject anticipate the action signal at a constant time interval after the alert signal and thus establish a rhythm of movement.

The time from alert signal to action signal was varied between two and eight seconds so that the subject did not develop a rhythmic movement nor did he treat the two signals as a single stimulus. This was in agreement with principles stated by Welford [1960].

Recording data and resetting the counter required at least ten seconds which insured that each trial was independent of the previous trial. This requirement to insure independence between trials was reported by Morgan [1963].

#### F. OTHER CONSIDERATIONS

To eliminate possible effects due to environmental changes the testing was performed in a windowless, air-conditioned room at the Naval Post-graduate School. The subject's field of vision was restricted by a plain wall to the left and plywood partitions higher than eye level to the front and right.

The experimenter, seated behind the subject, was in position to observe the subject and all the equipment.

Reaction time is faster for an auditory signal than it is for a visual signal [Teichner, 1954]. The difference in reaction times, on the order of 0.03 seconds, is small and in most applications, if not all, it is insignificant. The value of an auditory signal decreases when background noise is present [Morgan, et. al., 1963].

An auditory signal was given by the switch used to turn on the light. A radio, tuned to a local commercial station, provided background "noise" common in most privately owned automobiles and masked out the switch noise.

The testing sequence required 30 minutes per subject.

#### IV. RESULTS

The linear statistical model assumed for this experiment was:

$$T_{ijkl} = \mu + F_i + R_j + A_k + FR_{ij} + FA_{ik} + RA_{jk} + RFA_{ijk} + E_{l(ijk)}$$

where

$T_{ijk}$  is brake actuation time.

$\mu$  is the true mean for all observations,

$F_i$  is the effect due to floor angle (3 levels),

$R_j$  is the effect due to rotational angle (3 levels),

$A_k$  is the effect due to age (4 levels),

$E_{l(ijk)}$  is the random experimental error.

The other terms represent interactions between factors.

The null hypothesis was "there is no difference among the effects of floor angle, rotational angle, and age on brake actuation time."

Brake actuation time is the same time interval described by reaction time. The alternate hypothesis was that differences do exist among the effects.

A three way, fixed effect analysis of variance was the statistical method used to test the hypothesis. Except where specifically noted a significance level of 0.05 was selected.

Results of the analysis of variance showed that there was a significant difference in brake actuation time due to each of the factors. No interaction effects were found as shown in Table III.

To determine which of the factors differed a Duncan multiple range test [Hicks, 1966] was performed on data for each of the factors. Results of this test were:



TABLE III  
Three Way ANOVA - All Subjects

Treatment	Degrees of Freedom	Mean Square	F Value
Floor Angle (I)	2	71568.000	10.644*
Rotational Angle (J)	2	114240.000	16.991*
Age (K)	3	140784.000	20.939*
I x J	4	8648.000	1.286
I x K	6	2301.333	0.342
J x K	6	13053.332	1.941
I x J x K	12	3234.667	0.481
Error	1260	6723.488	
Total	1295		

\*Significant at  $p = 0.05$

i. Actuation times at floor angle settings of 55° and 65° were significantly faster than times at the 45° settings. No difference existed between settings of 55° and 65°.

ii. Actuation times at rotational angle settings of 0° and 15° were significantly faster than at setting of 30°. There was no significant differences in times between the other two angles.

iii. The youngest age group, group 1, was slowest. No differences were found among the other age groups. Results are summarized in Table IV.

Two way, fixed effects analysis of variance and Duncan Multiple range tests were performed separately on the data from each age group with the following significant results:

i. Age group 1: Actuation times at the 0° rotational angle were faster than at 30°.

ii. Age group 2: Actuation times at 0° and 15° rotational angles were faster than at 30°.

iii. Actuation times were faster at floor angles of 65° than at angles of 45°. There was no significant difference in time between settings of 65° and 55°, or between settings of 55° and 45°.

iv. Age group 4: Actuation times were faster at floor angles of 55° and 65°, and at rotational angles of 0° and 15°.

These results are summarized in Table V.

When evaluating data for all subjects simultaneously no simple linear correlation was found between brake actuation time and any of the following independent variables: ankle angle, seat reference distance, subject's height, or ratio of seat reference distance to subject's height.

TABLE IV

Duncan Multiple Range Test

	Floor Angle			Rotational Angle			Age Group			
	65°	55°	45°	0°	15°	30°	3	2	4	1
Factor Level	294.26	297.92	318.47	293.56	295.12	322.47	287.76	293.80	299.12	334.20
Mean Time										
Std. Error		3.945			3.945				4.555	
p	2	3		2	3		2	3	4	
Range	2.77	2.92		2.77	2.92		2.77	2.92	3.02	
LSR	10.928	11.519		10.928	11.519		12.617	13.301	13.756	
Test	65° vs 45° = 24.21*	0° vs 30° = 28.91*	3 vs 1 = 46.44*							
	55° vs 45° = 20.55*	15° vs 30° = 27.35*	2 vs 1 = 40.40*							
	65° vs 55° = 2.66	0° vs 15° = 1.56	4 vs 1 = 35.08*							
			3 vs 4 = 11.36							
			2 vs 4 = 5.32							
			3 vs 2 = 6.04							

\*Significant at  $p = 0.05$

TABLE V

Two-Way ANOVA by Age Group

Age Group	Degrees of Freedom	1		2	
		Mean Square	F Value	Mean Square	F Value
Floor Angle (I)	2	20160.000	2.1650	10504.000	1.6200
Rotational Angle (J)	2	40872.000	4.3893*	79080.000	12.1961*
I x J	4	4028.000	0.4326	6940.000	1.0703
Error	315	9311.691		6484.062	
Total	323				

\*Significant at  $p = 0.05$

Continuation of Table V

Two-Way ANOVA by Age Group

Age Group	Degrees of Freedom	3		4	
		Mean Square	F Value	Mean Square	F Value
Floor Angle (I)	2	24848.000	5.3198*	23016.000	3.5779*
Rotational Angle (J)	2	800.000	0.1713	32728.000	5.0876*
I x J	4	2460.000	0.5267	4868.000	0.7567
Error	315	4670.879		6432.863	
Total	323				

Significant at  $p = 0.05$



When analyzing data for each age group separately no correlation was found in group 1 or group 4. In group 2 a positive correlation coefficient of 0.392 was found for height and actuation time, and a negative correlation coefficient of -0.338 was found for ratio and actuation time. Seat reference distance and actuation time had a negative correlation coefficient of -0.332 in age group 3.

The minimum individual mean actuation time was 181.25 milliseconds at the  $45^{\circ}/0^{\circ}$  setting (floor angle/rotational angle), and the maximum individual mean actuation time was 681.75 milliseconds at  $45^{\circ}/30^{\circ}$ .

The fastest mean actuation time for all subjects combined was at a setting of  $55^{\circ}/0^{\circ}$ . The next three fastest in order were  $65^{\circ}/0^{\circ}$ ,  $65^{\circ}/15^{\circ}$ ,  $55^{\circ}/15^{\circ}$ . The difference between the first and fourth fastest times was 9.29 milliseconds (Table VI).

Frequency of favorable and unfavorable comments concerning a particular angular setting were tabulated. For the four settings with the fastest actuation times the frequency of each type response was analyzed using the non-parametric chi-square test. The hypothesis "that the proportion of favorable and unfavorable responses is the same for the four settings" was rejected at the 0.01 significance level. The proportion of favorable responses for the  $55^{\circ}/0^{\circ}$  and  $55^{\circ}/15^{\circ}$  settings is much higher. For the  $55^{\circ}/0^{\circ}$  setting there were eight favorable and zero unfavorable responses, and for  $55^{\circ}/15^{\circ}$  setting there were eleven favorable and two unfavorable responses. Unfavorable responses were greater by four to three at the  $65^{\circ}/0^{\circ}$  setting and by seven to six at the  $65^{\circ}/15^{\circ}$  settings.

TABLE VI

## Mean Brake Actuation Time

Setting	Overall	Grp 1	Grp 2	Grp 3	Grp 4
55/0	286.20	310. <sup>**</sup> <sub>31</sub>	276. <sup>*</sup> <sub>50</sub>	280.17	277.83
65/0	287.05	303. <sup>**</sup> <sub>97</sub>	280.33	276. <sup>*</sup> <sub>06</sub>	287.83
65/15	288.17	333. <sup>**</sup> <sub>72</sub>	275.75	261. <sup>*</sup> <sub>47</sub>	281.75
55/15	295.49	323. <sup>**</sup> <sub>33</sub>	275. <sup>*</sup> <sub>67</sub>	293.50	289.47
45/15	301.69	333. <sup>**</sup> <sub>00</sub>	275. <sup>*</sup> <sub>03</sub>	300.03	298.72
45/0	307.43	337. <sup>**</sup> <sub>28</sub>	286. <sup>*</sup> <sub>28</sub>	307.39	298.78
65/30	309.07	343. <sup>**</sup> <sub>94</sub>	307.69	279. <sup>*</sup> <sub>89</sub>	304.75
55/30	312.07	342. <sup>**</sup> <sub>72</sub>	312.69	290. <sup>*</sup> <sub>39</sub>	302.47
45/30	346.28	379. <sup>**</sup> <sub>55</sub>	354.25	301. <sup>*</sup> <sub>00</sub>	350.51

\* Fastest time

\*\* Slowest time

Mean seat reference distance was 37.74 inches. Mean height of subjects was 71.7 inches with a range from 66 inches to 77 inches. The ratio of these two variables ranged from 51.9% to 53.2% with a mean of 52.6%.

Age	Height	Weight	Seat Reference Distance	Ratio	Ratio
18-19	66-70	120-150	37.74	51.9%	53.2%
20-24	66-70	120-150	37.74	51.9%	53.2%
25-29	66-70	120-150	37.74	51.9%	53.2%
30-34	66-70	120-150	37.74	51.9%	53.2%
35-39	66-70	120-150	37.74	51.9%	53.2%
40-44	66-70	120-150	37.74	51.9%	53.2%
45-49	66-70	120-150	37.74	51.9%	53.2%
50-54	66-70	120-150	37.74	51.9%	53.2%
55-59	66-70	120-150	37.74	51.9%	53.2%
60-64	66-70	120-150	37.74	51.9%	53.2%
65-69	66-70	120-150	37.74	51.9%	53.2%
70-74	66-70	120-150	37.74	51.9%	53.2%
75-79	66-70	120-150	37.74	51.9%	53.2%
80-84	66-70	120-150	37.74	51.9%	53.2%
85-89	66-70	120-150	37.74	51.9%	53.2%
90-94	66-70	120-150	37.74	51.9%	53.2%
95-99	66-70	120-150	37.74	51.9%	53.2%



## V. DISCUSSION

Examining mean actuation times for each age group shows age group 1 is slowest at all nine settings. Age group 2 had the fastest mean actuation times at four settings, and age group 3 was fastest at five settings (Table VI).

Finding the group of youngest subjects to be the slowest group is contrary to results found in other age-reaction time studies. A possible explanation for this is the motivation factor, which is significant when system output is affected by operator performance [Morgan, et. al., 1963]. Most of the subjects in groups 2, 3, and 4 were students personally known by the experimenter. Subjects in group 1 were enlisted personnel assigned to support activities at the school. They had been randomly selected by pulling record books from a filing cabinet. Prior to reporting to the testing area they knew only that their reaction times were to be tested. The experimenter (an officer) explained the purpose of the test to motivate the subjects and attempted to put them at ease. He may not have been successful with group 1 subjects.

An analysis of variance was performed on data for groups 2, 3, and 4. Results showed that effects due to floor angle and rotational angle were still significant, but age effects were no longer significant. In addition an interaction effect of rotational angle x age became significant (Table VII).

Of the subjects commenting about a particular setting most stated that the ankle angle was too great at 45° floor angle. At floor angles of 65° the ankle angle was too small and put a strain on the calf muscles. At 30° rotational angle activation of the brake pedal was difficult

TABLE VII

Three-Way ANOVA - Age Groups 2, 3, 4

Treatment	Degrees of Freedom	Mean Square	F Value
Floor Angle (I)	2	52384.000	8.937*
Rotational Angle (J)	2	78576.000	13.406*
Age (K)	2	10416.000	1.777
I x J	4	7364.000	1.256
I x K	4	2976.000	0.508
J x K	4	17000.000	2.900*
I x J x K	8	3468.000	0.592
Error	945	5861.297	
Total	971		

\*Significant at  $p = 0.05$

because of the plane of movement of the leg. The direction of movement should be in line with the long axis of the lower leg and roughly parallel to the midplane of the body [Morgan, et. al., 1963]. Due to the design of the pedal this was not possible.

When subjects were placed in four groups based upon number of years driving the composition of each group was approximately the same as when grouping was based upon age only. Analysis based upon number of years driving would be the same as a similar analysis based upon age. Therefore, an analysis based upon driving experience was not performed.

The design of most small foreign automobiles makes it impossible for the driver to rotate his foot to the right when depressing the accelerator. In most American automobiles it is possible to rotate the foot to the right while depressing the accelerator and still have the right foot in position to use the brake. It was assumed these possibilities would influence preferred angular setting.

Subjects were not required to make comments concerning any angular setting and many did not do so. There was insufficient data to determine if any correlation existed between type of car design and preferred angular setting.

## VI. CONCLUSIONS

The fastest brake actuation time for all subjects was 286.2 milliseconds at an angular setting of  $55^{\circ}/0^{\circ}$ . This is a 35% reduction in time when compared with the fastest brake actuation time reported for conventional braking systems. For an automobile initially traveling at 60 mph the required stopping distance is reduced 14.4 feet which is the equivalent of adding one car length between vehicles at the time a danger signal is sensed. This savings in stopping distance may be sufficient to prevent an accident. If not, at least the severity of the accident will be reduced due to smaller impact forces at the time of collision.

Reaction times observed in this experiment are slower than those observed by West [1969]. However, these times are 11% faster than times reported for other combined pedals.

The best angular settings for the combined pedal are  $55^{\circ}/0^{\circ}$  and  $55^{\circ}/15^{\circ}$ . The mean brake actuation times at these settings are not significantly different and the subjects responding preferred these settings.

The mean ankle angle of  $83^{\circ}$  is in close agreement with the  $84^{\circ}$  recommended by Ayoub and Trombley [1967].

Morgan, et. al., [1963], recommended that for greater comfort the seat reference distance should be 55% of the operators height. The observed mean ratio for this experiment was 53%.



## VII. RECOMMENDATIONS

Additional experimentation is required before this combined brake-accelerator pedal can be mounted in a vehicle and road tested.

Floor angle increments were  $10^{\circ}$  and rotational angle increments were  $15^{\circ}$ . Brake actuation times should be evaluated at a  $50^{\circ}$  floor angle, and at  $5^{\circ}$  and  $10^{\circ}$  rotational angles.

There was a vertical distance of approximately 11 inches between the height of the seat at the front edge and the height of the heel of the pedal. This distance is equivalent to 15% of mean height of subjects. The effects of vertical seat adjustment on brake actuation time should be investigated.

The pedal should be modified to permit movement of the leg in a plane parallel with the midsaggital plane of the body.

The platform on which the pedal is mounted should be modified so that the left foot is at the same height as the right foot.



## APPENDIX A

### INSTRUCTIONS TO SUBJECTS

The ultimate objective of this experiment is to increase automobile safety, primarily in military vehicles.

The series of tests you will perform today are part of a larger program to evaluate the optimum type, position, and functioning of combined brake-accelerator pedal. Previous testing has led to the selection of this pedal as the best design. I am attempting to determine the best positioning of the pedal.

### PROCEDURES:

You will be seated here and I will be directly behind you. When you press on the toe of the pedal you are simulating the accelerator. When I ask you to accelerate please press on the pedal so that this needle is between the two red lines. When you have done this I will give you "stand by" which is the warning signal. Within a matter of seconds I will turn on the red light directly to the front. This will also begin the timer. The light is the signal to apply the brake to simulate stopping the car. When you push in with your heel the pedal will contact a microswitch which will turn off the light and stop the timer.

I will be changing the angle between the pedal and the floor and the angle of rotation of your foot as it turns from a position straight up toward the right. In all there are nine different settings and at each of the settings you will be tested four times.

At each change of rotational angle you will be given three practice runs to get the feel of the pedal. It is important that you keep your heel flat on the pedal and push straight in when simulating the brake.

In addition to the timing I will be measuring the angle between your leg and your foot, and the distance from the seat to the pedal. These measurements will be made for each change in pedal position.

You may rest your foot and leg between trials, that is you don't have to keep it on the pedal.

This is not a race against other personnel but against time to determine average reaction times for various pedal settings.

If at any time you have a comment or an idea please tell me. Even if you feel it is unimportant when taken with other comments it may be very important.

## BIBLIOGRAPHY

1. Ayoub, M. M. and Trombley, D. J., "Experimental Determination of an Optimal Foot Pedal Design," Journal of Industrial Engineering, V. 18, 9, p. 550-559, 1967.
2. Belzer, E. G., "The Quickness of Selected Automobile Braking Methods," University of Illinois, 1965.
3. Bennett, E. M., Degan, J., and Spiegel, J., Human Factors in Technology, McGraw-Hill, 1963.
4. Davies, B. T. and Watts, J. M. Jr., "Preliminary Investigation of Movement Time Between Brake and Accelerator Pedals in Automobiles," Human Factors, V. 11, No. 4, p. 407-409, August 1969.
5. Hicks, C. R., Fundamental Concepts in the Design of Experiments, Holt, Rinehart and Winston, 1966.
6. Konz, S. and Daccarrett, J., "Controls for Automotive Brakes," Highway Research Record Number 195, Highway Research Board, Washington, D. C. 1967.
7. Konz, S., Kalra, G., and Koe, B., Human Engineering Design of a Combined Brake-Accelerator Pedal, paper presented at 9th Annual Symposium Human Factors in Electronics, Washington, D. C., 7 May 1968.
8. McCormick, E. J., Human Factors Engineering, McGraw-Hill, 1964.
9. Morgan, C. T., and others, Human Engineering Guide to Equipment Design, McGraw-Hill, 1963.
10. Ostle, B., Statistics in Research, The Iowa State University Press, Second Edition, 1969.
11. Siegel, S., Non-Parametric Statistics for the Behavioral Sciences, McGraw-Hill, 1956.
12. Teichner, W. H., "Recent Studies of Simple Reaction Time," Psychological Bulletin, V. 51, No. 2, p. 128-144, 1954.
13. Welford, A. T., "The Measurement of Sensory-Motor Performance: Survey and Reappraisal of Twelve Years Progress," Ergonomics, V. 3, No. 3, p. 182-230, 1960.
14. West, A. E., Effect of the Integrated Brake-Accelerator Pedal on Reduction of Brake Actuation Time, M. S. Thesis, Naval Postgraduate School, Monterey, California, September 1969.

15. White, A. J., Brake Dynamics, Research Center of Motor Vehicle Research of New Hampshire, 1963.



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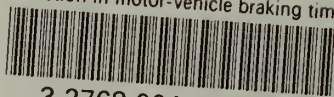
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